1.—CRETACEOUS STRATIGRAPHY OF LOWER MURCHISON RIVER AREA, WESTERN AUSTRALIA

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I. INTRODUCTION.

The latest available geological map of Western Australia, published in 1933 by the Geological Survey of Western Australia, shows an area of Cretaceous rocks extending northward from the mouth of the Murchison River almost as far as Shark Bay, that is between 27°40′ and 26°30′ S. lat. As practically nothing was known about the succession, thickness, lithology, and fossils of the rocks in this area it had long been our desire to investigate the geology of the lower Murchison River where good outcrops in these little known strata were reported to exist. After a preliminary visit to parts of the area by the junior author in 1943, our wish was finally realized in August, 1944.

1. PREVIOUS WORK.

As early as 1907 the occurrence of sedimentary strata along the lower part of the Murchison River was noted by Maitland who described

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how, about 20 miles east of the sea coast the river enters a narrow gorge, flanked by vertical walls of sandstone and grit. "The junction between these sandstones and the older gneissic rocks (to the east), as can be seen by a section on the north bank of the river, is a fault dipping to the west. This sedimentary formation occupies the whole of the Murchison Valley as far as Gantheaume Bay." This fault had been discovered by Maitland on an earlier occasion. In 1898, he stated that in the vicinity of Hardabut Pool, on the Murchison River, sandstones and grits are exposed a few yards from gneissic and schistose rocks and that the junction between the two series is a fault dipping west. However, Maitland did not then realize the extent of the sedimentary area to the west of this fault.

Neither in 1898 nor in 1907 does Maitland give any indication of the possible age of the sandstone series, but in 1919 he referred to it briefly in connection with a description of the Jurassic rocks of Western Australia.

Jutson, in 1934, quoted Maitland's observations and was puzzled by the appearance of a deep gorge in this country. The reason for this, he said, is not apparent.

The first indication of the presence of fossiliferous rocks in the area was in November, 1929, when Mr. L. Glauert of the Perth Museum received some fossils, collected on Murchison House Station. These he found to be identical with species from the Gingin chalk. Nothing was published about this occurrence, except a brief notice in the local press.

In 1932, the country near the mouth of the Murchison River was visited separately by E. S. Simpson and F. G. Forman. Dr. Simpson, who had been attracted by a report of phosphatic rocks, spent a few days at Murchison House, five miles from the mouth of the river, and in 1934 published a note on apatite, barite, and glauconite from these beds. In this connection he stated that the Murchison River flows for about fifty miles through a deep gorge before reaching Gantheaume Bay. "The walls on the south side of this gorge are about 800 feet high and consist essentially of reddish sandstone (Jurassic?). The north side is somewhat higher, the sandstone being overlaid by glauconitic sands and shales, and finally capped by chalk, both of proved Cretaceous age." This latter piece of information was based on an examination by Mr. L. Glauert of some fossils collected by Dr. Simpson, but no fossils were mentioned by name in Simpson's paper.

Mr. Forman crossed the Murchison on camels, travelling from the south towards Shark Bay, but the full report of his trip has never been published. Reference was first made to it in a paper by Hobson in 1936 who says that Forman found Cretaceous sediments overlying a sandstone series, the whole sequence dipping 1° or 2° west. Forman himself briefly referred to his observations in a report in 1937, when he proposed a tentative correlation of the lower sandstones with the Permian Kennedy sandstones which had then become known from Raggatt's investigations (1936) in the Carnarvon Natural Region. He recognised the Cretaceous age of the beds overlying this sandstone series and noted the occurrence, in the vicinity of Mt. Curious, of fossiliferous chalk containing *Trigonosemus*, *Cidaris*, *Inoceramus*, *Ostrea*, and other fossils.

In subsequent years the junior author frequently crossed this same area by aeroplane; the senior author had already seen it from the air in 1927. From these observations it was clear that the lower sandstones which could be seen outcropping all along the bottom and the sides of the Murchison River valley were overlain by a series of whitish rocks which formed an escarpment a few miles north of the river and more or less parallel to it. These white cliffs extended inland at least as far as the telegraph line, more than 16 miles upstream from the coast, and since Simpson's discovery of chalk in the vicinity of Murchison House Homestead the conviction grew that these cliffs in their entirety were more or less composed of the same kind of rock.

In March 1943 the British Phosphate Commissioners decided to investigate in somewhat greater detail the phosphate occurrences described by Simpson and the junior author was fortunate enough to be invited to accompany the Government Geologist of Western Australia, Mr. F. G. Forman, and the representative of the British Phosphate Commissioners, Mr. J. C. Dulfer, on an exploratory trip which took place in March of that year. The approach to the sedimentary area was made from the east, entering the country from the Northampton-Carnarvon road, but very bad conditions were encountered and it was only with difficulty that the party reached the telegraph line at a small, now abandoned, emergency aerodrome, four miles north of Bettie, where the telegraph line crosses the river. It was soon found that the country was virtually impassable for motor cars and since the party was not equipped for any other form of transport its radius of activity was small and the results of the trip limited. However, the country along the telegraph line was examined in some detail from the river bed as far as the white cliffs in the vicinity of the aerodrome, more than four miles from the river. The lower sandstones were found to be strongly cross-bedded and the cliff section was found to consist of glauconitic sands, glauconitic shales and siliceous shales, overlain by chalk which contained a typical Upper Cretaceous (Senonian) fauna, including *Cintaerinus* and *Marsupites*, identical with the well-known chalk fauna of Gingin, 280 miles to the south. In addition, several localities up to a distance of about 20 miles east of the telegraph line were examined, especially the vicinity of Weeriuoogudda Dam, the upper part of Bungabandy Creek, and the country as far as Warranjababba Spring.

2. Present Investigations.

In August, 1944, we were enabled to visit the Lower Murchison River Area and, in the sixteen days at our disposal, we tried to obtain a general picture of the geology of the main valley and its tributaries from the coast to a little beyond the Geraldton-Carnarvon telegraph line. We also saw something of the coastline from the mouth of the river to a point about ten miles farther north.

This work was made possible by an invitation from Messrs. Hubert Evans and A. J. Sims of Evans, Mawley and Sims who provided motor transport from Northampton to Murchison House homestead, a distance of seventy-two miles and, on the return journey, from the homestead to Geraldton, a distance of more than one hundred miles. On arrival at the homestead a native guide, and riding and pack horses were placed at our disposal for the entire duration of our stay. The first week was spent in camp at Buhu windmill with Mr. Tom Pepper and his family

whose interest and local knowledge greatly expedited our work. It is our pleasant duty to record here our indebtedness to Messrs. Evans and Sims, to Mr. F. Blood, manager of Murchison House Station, and to Mrs. Blood for their hospitality, and to the others on Murchison House Station who were always eager to help us in our work.

Overlapping vertical aerial photographs, covering the entire area of our survey were made available to us by the Department of the Army. Unfortunately, we did not learn of their existence until after our return from the field. They were, however, invaluable in the final preparation of this report.

3. Geographical Notes.

The Murchison is one of the major rivers of Western Australia and is intermittent, as are all rivers in this State between 18° and 30° south latitude. It rarely floods more than once or twice in a year. It rises about 350 miles inland and after traversing the Pre-Cambrian shield for the first 275 miles of its course it enters an area of sedimentary rocks near Bompas Hill (about 115° 20′ east longitude). Here the river bends sharply and pursues a general south-west course. At Rocky Pool about 45 miles south west from Bompas Hill it enters Pre-Cambrian rocks which persist through Galena to Hardabut Pool, which is about 16 miles south-west of Rocky Pool. Near Hardabut Pool the river turns sharply north and traverses a series of sandstones which is an extension of the Tumblagooda Sandstone described in this paper.

Below Hardabut Pool the river enters a gorge which extends down-stream almost as far as Mt. Curious where it turns south-west and flows to the Indian Ocean in a fairly wide valley. On the north-west side of this part of the river the country rises to a plateau about 600 feet above sea-level which breaks off towards the river in a steep scarp about 200 feet high formed of Upper Cretaceous shales, chalk, and sandstone (text figs. 13 and 14). The edge of the scarp is broken by broad valleys (Plate I). Its top is protected by "durierust," on the average about 15 feet thick which is somewhat discontinuously covered by sand, making the plateau look like a sand plain, although the crust is close to the surface and crops out in many places.

The plateau on the south-east side of this part of the Murchison River is somewhat lower (text fig. 7) probably averaging about 450 feet above sea-level, but Meanarra Hill, an erosion remnant, rises to about 590 feet (text fig. 5). The surface of this plateau is sandy and we did not notice any outcrops of durierust such as are frequent on the higher plateau. There is, however, a lateritic layer below the sandy surface; this is the laterized top of the Tumblagooda Sandstone which underlies the entire country south of the river mouth and west of the great bend of the river. Good exposures showing the gradual transition from the sandstones to the laterite can be seen in gravel pits close to the point where the road from Murchison Homestead to Ajana reaches the general plateau level. The laterite is overlain by several feet of sand which make very "heavy going" for motor vehicles.

The area which we investigated forms part of Murchison House Station. It can be reached by motor over a very sandy track from Ajana, the nearest railway station, 35 miles to the south. Apart from

this track the country is impassable for motor vehicles of the ordinary type.

II. GENERAL GEOLOGY.

The Cretaceous rocks fall readily into two divisions; a lower of sandstone, mostly reddish and cross-bedded, and an upper of softer, more easily eroded rocks, such as loosely cemented sandstones, shales, and chalk. As already noted the Murchison River enters a deep sandstone gorge at the point where it leaves the Pre-Cambrian rocks north of Ajana. Some glimpses of this gorge can be obtained from the road leading from Ajana to Murchison House Station, particularly in the vicinity of Pine Thicket rain-shed, about 15 miles N.W. of Ajana and about the same distance S.E. of Meanarra Hill. The valley here is shallow and wide and the river occupies an over-deepened gorge of which only the upper part is visible from the rain-shed. This gorge apparently continues to a point south of Mt. Curious, but farther west the valley widens and erosion has cut more deeply into the lower sandstones all the way from Bettie Crossing to the sea shore.

On the north-western side of the river, in this last part of its course, the strata dip 2°-3° to the N.W. Occasional dips of as much as 5° have been measured, but these are exceptional. No dips were measured on the south-eastern side of the river.

South-east of the river in this part the belt of exposed sandstone is not more than a mile wide, and in many places it is less, whereas north-west of the river it is rarely narrower than two miles, and, in many places is as much as four miles wide. This suggests a regional north-westerly dip.

One of the most noticeable features of the sandstone belt on both sides of the river is the jointing. We noticed the presence of many parallel vertical joints but did not have time to study this feature more closely. The influence of jointing on the topography becomes very clear on inspection of the aerial photographs.

Text Fig. 1.

Geological section the Murchison valley from Meanarra Hill to the vicinity of Second Gully (for location see Plate II.).

The strike of the joints is between 130° and 140°. Over wide areas differential erosion has taken place along them and consequently the outcrops are channelled by innumerable parallel furrows. On the photographs it can be seen that they are from about 200 to 400 feet apart. Often they can be followed from deeply eroded into less eroded country, where they may only be indicated as strips of slightly denser vegetation. On the ground we observed the presence of numerous open joints with their walls as much as four feet apart. In many places it seemed that they were due to tensional movements rather than to erosion.

From the air it can be seen that the characteristic N.W.-S.E. jointing becomes less conspicuous a short distance S.E. of Mt. Curious and still higher upstream is completely replaced by a system of prominent E.-W. joints which becomes more and more marked towards the boundary of the sandstone area near Hardabut Pool.

The overlying softer rocks are exposed along an escarpment about two to four miles north-west of the river. They underlie the plain to the north probably as far as Shark Bay. Along the escarpment, gullying is active almost everywhere, and on the whole the escarpment is probably receding at a fairly rapid rate. That this upper series once extended across the river towards the south is shown by the occurrence of these rocks at Meanarra Hill which forms an erosion remnant about four miles south of the river (text fig. 5).

The escarpment on the north side approaches the sea coast about five miles north of the mouth of the Murchison River, where it turns in a direction more or less parallel with the coast. The distance between the top of the escarpment and the shore is at first a mile or so, but diminishes gradually until, north of Nungajay Spring, it is not more than about 500 yards. Exposures along the coast are exceedingly poor owing to a covering of slipped duricrust on the slopes. There are chalk exposures in a few places, but the nature of the overlying and underlying beds can rarely be ascertained.

Text Fig. 2.

View across lower part of Second Gully from slope below Alinga Point. Lower shelf is Tumblagooda Sandstone partly covered with loose sand, probably disintegregrated Butte Sandstone. In the distance is the scarp of the upper part of the Murchison House Series (Alinga Beds to Second Gully Shale). (Traced from photographs.)

III. CRETACEOUS STRATIGRAPHY.

(Murchison House Series.)

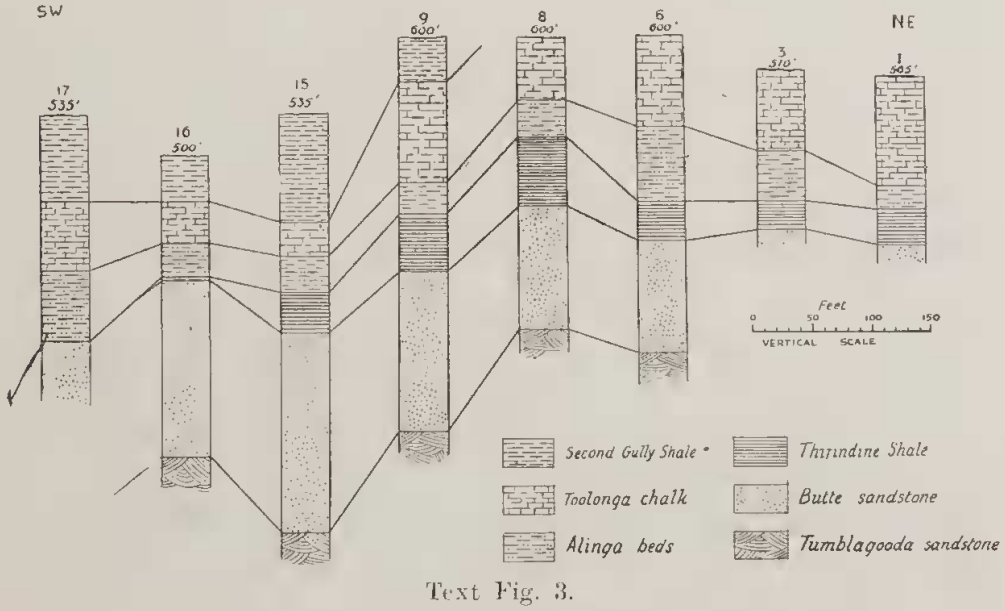
1. General.

The name Murchison House Series is here proposed for the succession of sedimentary rocks which occurs on both sides of the Murchison River from the coast of the Indian Ocean eastwards to at least a few miles east of the telegraph line i.e. for a distance of about 18 miles. The eastern boundary of the outcrop area of this series has not yet been determined. Southwards the sediments disappear a short distance from the river under a cover of loose sand, but outcrops exist along the coast at least as far as Bluff Point (text fig. 6) and very probably they continue still farther to the south. North of the river the sediments likewise are covered by sand, but, along the coast, outcrops were observed to a point ten miles north of the mouth of the river and they seem to extend considerably farther north.

All good outcrops of the series and all sections studied by us occur on Murchison House Station.

The following subdivisions of the Murchison House series are here proposed :—

Name.	Lithology.	Fossils.	Thickness in feet.
Second Gully Shale	Light green glauconitic shales	...	92+
Toolonga Chalk	Mostly pure chalk, sometimes glauconitic ; in many places with a 6in. layer of phosphatic nodules at the base and usually rich in chert nodules in the upper part.	Foraminifera, *Ciduris*, *Marsupites*, *Uintacrinus*, *Gryphaea*, *Inoceramus*, brachiopods	35–120
Alinga Beds	Glauconitic shales, often sandy and with greensand pockets, grading into greensand	Belemnites	10–75
Thirindine Shale	Whitish to grey, siliceous shale, sometimes more massive and grading into siltstone	Very poor belemnite fragments, rare	0–63
Butte Sandstone	Predominantly unbedded pure quartz sandstone, mostly loosely cemented or incoherent ("running sand") ; uppermost part usually ferruginous and glauconitic	Vertical and oblique burrows, fossil wood (rare)	75–170
Tumblagooda Sandstone	Predominantly reddish and purple sandstones, as a rule strongly cross-bedded, but grading into well-bedded sandstones above	Vertical burrows and invertebrate trails on bedding planes	400+



Text Fig. 3.

Selected columnar sections of the Murchison House Series above the Tumblagooda Sandstone. The positions of these and other measured sections are indicated on Plate II.

Thickness.—Owing to the fact that the base of the Tumblagooda Sandstone is not exposed and also because of the lateral variations in thickness of most of the higher stages of the series, it is somewhat difficult to give a reliable estimate of the total thickness of the Murchison House Series. Near the northern end of Second Gully 355 feet of sediments are exposed above the top of the Tumblagooda sandstone. However, some members of the series, particularly the Toolonga Chalk and the Alinga Beds, are thinner here than elsewhere, so that the total thickness of the beds in other sections might well be somewhat greater. To this must be added the minimum thickness of the Tumblagooda sandstone (400 feet). It may then be concluded that the minimum thickness of the Murchison House Series in the area surveyed by us is at least 750 feet.

2. Tumblagooda Sandstone.

Derivation of name.—Tumblagooda Hill, on the coast two miles north of the mouth of the Murchison River, about 290 feet high, where a typical section is exposed.

Areal distribution and outcrops.—The Tumblagooda Sandstone crops out on both sides of the Murchison River (text fig. 4). On the south-east

Text Fig. 4.
River flat near Tutula windmill showing hillocks of Tumblagooda Sandstone.

side the outcrops disappear at the edge of the sand plain at about 400 feet above sea level, in most places about a mile or so from the river bed. On the north-west side the belt of outcrops is wider, in places up to four miles wide, and towards the north the Tumblagooda Sandstone disappears under the Butte Sandstone and higher formations. The outcrops are generally good. The sandstone is strongly dissected by erosion and can be studied in numerous cliffs along the river, along hill slopes, and in the many tributaries.

The Tumblagooda Sandstone must have a wide distribution outside the area of our investigations. It seems to form the coastal cliffs as far south as one can see from Tumblagooda Hill and other elevations north of the Murchison River, that is for at least 12 miles as far as and beyond Bluff Point, but probably much farther (text figs. 5, 6, and 7). No outcrops of the sandstone can be seen along the coast north of Tumblagooda Hill, the lower parts of the coastal cliffs being here entirely covered with younger formations (sand and "coastal limestones"). In an easterly direction the Tumblagooda Sandstone certainly continues beyond Mt. Curious—we mentioned under "Previous Work" the deep gorge cut by the Murchison River, and the formation can be followed along Bungabandy Creek and still farther east. It was seen by the junior author in 1943 as far east as Warranjababba Spring, 19 miles E.S.E. of Mt. Curious. Maitland reports that west of Geraldine at Hardabut Pool, in the great southern bend, the sandstone is faulted down against pre-Cambrian rocks, and, though the geology along the Murchison River downstream from Hardabut Pool to the area which we have mapped has

Text Fig. 5.
View from one of the low hills in Fig. 4 looking south across Murchison River to Meanarra Hill.

Text Fig. 6.
Looking south from sand hills west of Tumblagooda to Bluff Point which is probably Tumblagooda Sandstone.

Text Fig. 7.
Looking south-east from the scarp just north of Thirlindine over the Murchison valley to the sandplain which is underlain by Tumblagooda Sandstone.

not been studied, from the air it can be seen that outcrops of sandstone are continuous on both sides of the river as far as Mt. Curious.

Scope.—The base of the Tumblagooda Sandstone is not exposed anywhere within the map area. Its upper limit though not as a rule well

exposed, is clearly defined by a succession of well-bedded reddish and white sandstones and the contact with the overlying unbedded, incoherent lower part of the Butte Sandstone is sharp and well marked.

Lithology.—Seen from a distance outcrops of the Tumblagooda Sandstone have the appearance of being very thick-bedded, with bedding planes ten or twenty or more feet apart, but closer inspection shows that nearly all these thick beds are very strongly and irregularly cross-bedded (text fig. 8). The bulk of the sandstone is reddish to purplish in colour, but in many places, where it is very finely laminated, white layers alternate with red. On the whole the sandstone is medium-grained

Text Fig. 8.

Typical Tumblagooda Sandstone near foot of east side of Tumblagooda showing cross-bedding and (above and to right of pick) worm burrows. Honeycomb structure in upper right corner is due to weathering, not to worm burrows.

with grains up to 1 or 2 mm. diameter. The components are predominantly quartz grains. Bands of pebbles of varying sizes, up to 1 or 2 cm. diameter are not uncommon, but larger pebbles of several centimetres in diameter are rare. Many of these large pebbles are surrounded by

bleached zones as much as 10 cm. wide. Bleached spherical spots of anything up to 2 or 3 cm. diameter may also appear anywhere in the reddish sandstone.

As regards the cross-bedding, the impression was in general that the prevailing dip was in a westerly direction. We had not time to get sufficient data for a thorough statistical analysis, but about 50 measurements in the vicinity of Murchison House Homestead suggest that the source of the sediments, at least in this locality was approximately from the E.S.E. The dip of the cross-bedding rarely exceeds about 20°

Towards the top the cross-bedded sandstones change gradually into well bedded, more shaly sandstones (text fig. 9.) The transition is very gradual: At first a few horizontally bedded sandstone layers are intercalated between strongly cross-bedded strata; then the horizontally bedded layers become thicker and more numerous and frequently shaly, and cross-bedding becomes subordinate; also the red colour becomes less prominent, the horizontally

Text Fig. 9.
Well-bedded sandstones above Nats Flat (marked on Plate I.) forming the top part of the Tumblagooda Sandstone.

bedded layers being either whitish or brown. This transition zone was only seen well in a few places, e.g. in the Pillarawa section and at Second Gully Point, where it is approximately 20 feet thick. In many places detritus derived from the rather incoherent overlying Butte Sandstone conceals the higher part of the Tumblagooda Sandstone. At Tumblagooda Hill itself the upper part of the sandstones is well exposed and here includes a 20-foot band of rather massive brownish, strongly cross-bedded sandstone which is intercalated in the well-bedded series, and makes the transition zone at least 60 feet thick in this place.

The sandstones exposed east of Mt. Curious, in the upper reaches of Bungabandy Creek and in the vicinity of Warranjababba Spring are fine-grained and thin bedded and cross-bedding is not much in evidence. It is at present impossible to say whether these are exposures of the normal facies of the top section of the Tumblagooda Sandstone, or whether a change in the character of the whole formation takes place in an eastward direction.

Fossils.—The only fossils in this sandstone are invertebrate tracks and vertical burrows. The latter are particularly prominent and occur at many horizons throughout the entire sequence. They were observed in more detail in the vicinity of "Stone Wall" at the foot of Toolonga Point, in the outcrops below the cliffs between Thirindine and Toolonga, in Second Gully, and in the Tumblagooda Hill section where several horizons with many burrows were seen. The burrows now form cylinders which are either filled with sandstone of a different colour from that of the surrounding rock, (for example they may consist of red sandstone penetrating laminated red and white rock), or are merely made evident on cliff sides by differential weathering. They are always vertical and generally have a diameter of one half to one inch, although diameters up to two inches have been observed. They may be up to eight inches long, but are mostly shorter. They are generally restricted to sandstone layers which are two to four feet thick, and there is usually a considerable thickness, rarely less than 20 feet, between successive burrow horizons.

The burrows are frequently rather crowded: in one horizon in the Tumblagooda Hill section 100 burrows were counted on a surface measuring 50 x 50 cm. On the bedding planes the place of a burrow is indicated by a little mound.

Invertebrate tracks along bedding planes have been observed only in one locality, a low hill east of Tutula windmill where the inclined bedding planes of the cross-bedded sandstone are densely covered with meandering trails which are six to eight mm. wide and stand out in low relief above the bedding plane; they are characterized by a sharp furrow in the middle and may have been made by gastropods.

Thickness.—Since the base of this sandstone has not been discovered its true thickness cannot be stated. The plateau level on the south-east side of the river is about 400 feet above the sea and this may be taken as the approximate maximum exposed thickness in the area of our investigations. This, however, must be taken as a minimum figure, for by extending the survey towards the south-east a somewhat greater thickness would probably be obtained.

3. Butte Sandstone.

Derivation of name.—Small prominent conical hill (butte) on south side of Second Gully (text fig. 10), where the greatest thickness (170 feet) of this sandstone was measured.

Text Fig. 10.

Second Gully seen from the north. In the centre is the butte with capping of Thirindine Shale, underlain by Butte Sandstone which extends nearly to the valley floor. The scarp on the other side of the valley consists of Toolonga Chalk and Second Gully Shale. In the foreground is the hardened surface (duricrust) of the latter.

Areal distribution and outcrops.—The Butte Sandstone forms the base of the scarp everywhere north of the Murchison River and can be traced all the way from the telegraph line to Mullewa Point, a mile or so from the coast. From the foot of the scarp there extends a strongly dissected shelf of varying width which is covered with loose sand, consisting, at least in part, of disintegrated Butte Sandstone (text fig 2). Although part of this loose sand may be derived from the top layers of the Tumblagooda Sandstone, the whole of this shelf area has been included on our map in the upper part of the Cretaceous series which begins with the Butte Sandstone. The Butte Sandstone is not exposed along the coast, where it is probably buried under younger deposits of sand and "coastal limestone." There is reason to snppose that it forms the base of Meanarra Hill, south of the Murchison River, but no exposures have been seen.

Scope.—The base of the Butte Sandstone is rarely well exposed, though it is sharply defined by the sudden change from the thin-bedded uppermost layers of the Tumblagooda Sandstone. The upper boundary with the Thirindine Shales is mostly sharp (text fig. 11), though occasionally a more gradual transition can be detected on closer inspection. The

Text Fig. 11.

Butte Sandstone and Thirindine Shale in scarp just west of emergency landing-ground. The boundary between the two formations is marked by *X*. The top layer of the Butte Sandstone is here somewhat ferruginous and, therefore, harder.

Butte Sandstone thus includes all the strata between the uppermost layer of the well-bedded upper part of the Tumblagooda Sandstone and the base of the grey, siliceous, and mostly whitish-weathering Thirindine Shales.

Lithology.—Lithologically the Butte Sandstone is rather uniform throughout, being generally a whitish, unbedded, and incoherent deposit of quartz grains—in most places, indeed, a "running sand." The quartz grains have diameters of up to 3 mm. In the Toolonga section traces of cross-bedding can be seen, as well as occasional pebble bands with little pebbles not more than about 6 mm. across. In the Thirindine Point section the base of the Butte Sandstone is a deposit of three feet of massive, well cemented, mottled sandstone, with ferruginous patches and

large quartz grains. In view of the fact that the base of the Butte Sandstone is in general not well exposed, being buried under loose material slid down from above, it is not known whether this mottled sandstone zone has a very wide distribution.

In the uppermost 10 feet or so the loose quartz sand changes into glauconitic and ferruginous loosely cemented sandstone.

South-west of Toolonga Point, at Thirindine, and in the gully north of Yalthoo windmill there is a somewhat gradual transition to the overlying Thirindine Shales; the quartz sand first becomes glauconitic, and the size of the quartz grains gradually diminishes until the deposit becomes a glauconitic clay; then the glauconite disappears and the transition to the overlying shales is complete. Farther south-west, at Second Gully Point, the boundary with the overlying shales is better marked, the top of the Butte Sandstone being a brown loose sand with ferruginous concretions.

Fossils.—Fossil wood was found in a few places in the uppermost two feet of the Butte Sandstone, notably to the south-west of Toolonga Point and at Thirindine Point. Some of the wood fragments are riddled with cylindrical burrows, probably made by a *Teredo*-like mollusc. Their presence suggests that the wood must have drifted for some time before it became embedded in the sand. Very poor silicified belemnite fragments were found in the cliffs west of the emergency aerodrome four miles north of Bettie. Definitely recognizable tracks and burrows were only seen in one place in the hard quartz sandstone layers near the top of the Butte Sandstone in the Pillarawa section. Vertical and oblique burrows, up to one inch wide, penetrate this sandstone bed to a depth of one to 10 inches. On the bedding plane the entrance to these burrows is surrounded by circular walls which are two to three mm. high. In addition, the bedding plane is covered by a network of shallow, sometimes winding, but more often straight furrows, obviously the trails of some crawling invertebrates. Most of these trails seem to bypass the openings of the vertical burrows, but some issue from them, so that it is reasonable to assume that both burrows and trails have been made by the same kind of animal, most probably a worm.

In the running sand of the Toolonga section long tube-like structures were observed which are about five mm. wide and up to 10 and 15 cm. long and are either vertical or inclined up to an angle of 60°. They are formed of sand grains which are very loosely cemented and are occasionally brought out by weathering, the surrounding matrix being quite incoherent. It is believed that these structures are also due to the activities of some burrowing animals.

Thickness.—The thickness of the Butte Sandstone varies rather considerably. In the Pillarawa section it is about 100 feet, farther east the sandstone is not sufficiently well exposed for measurements of thickness to be taken. Farther west in the Toolonga Hills the thickness increases from 75 to 105 feet in a westerly direction. From there it increases probably rather regularly until it reaches 170 feet at the butte in Second Gully, the maximum thickness measured, and 152 feet at Second Gully Point. At Meanarra there must be about 50 feet of Butte Sandstone.

4. Thirindine Shale.

Derivation of name.—Thirindine is the name of a prominent point in the scarps north-west of the Murchison River, due north of Yalthoo Windmill.

Areal distribution and outcrops.—The Thirindine Shale crops out all along the scarps north-west of the Murchison River. It can be traced almost without interruption from Second Gully Point in the south-west to a point about one and a half miles east of the telegraph line where the outcrops disappear under the vegetation cover and have not been traced farther east. In 1943, however, the junior author located an extensive outcrop area of these shales in the vicinity of Weerinoogudda Dam, about eight to nine miles farther N.N.E., whence it continues for a distance of about six miles to the south-east along the track to Warranjababba Spring as far as a point about six miles north-east of Mt. Curious and about four miles north of Bungabandy Creek, near the eastern boundary of Murchison House Station. From the air it can be seen that good outcrops of the shale extend N.E. and E.N.E. of Weerinoogudda Dam for a distance of three to four miles. In the west, the Thirindine Shale is absent west of Second Gully Point and in the interior of Second Gully, but south of the Murchison River small patches were found on the north side of Meanarra Hill.

Scope.—The Thirindine Shale is always easily recogonizable because it weathers with a whitish surface. Its lower boundary is mostly fairly well defined, although in certain places there is a transition zone, one or two feet thick, from the underlying Butte Sandstone. The upper bounday against the glauconitic Alinga Beds is mostly quite sharp.

Lithology.—The Thirindine Shale is a very fine-grained deposit, usually of greyish colour. In places it consists of alternating softer and harder layers, the latter usually being whiter. However, the softer, greyish layers also harden on exposure and form a whitish surface. This surface-hardening causes the Thirindine Shale to be less easily eroded than the softer sediments above and below, so that it forms a characteristic terrace in the profile of the slopes along which it crops out.

In some places, the shale contains some glauconite. This is particularly marked in the scarp on the north-east side of Second Gully where its glauconite content increases gradually upwards so that there is a transition to the overlying glauconitic Alinga Beds. Glauconite was also observed elsewhere in the Thirindine Shale, for example in the Toolonga Hill section, but it is usually subordinate.

Fossils.—Remains of fossils were found only in the lower part of the shale at Toolonga Hills, where hard bands contain cavities left by belemnite guards which have been dissolved by circulating waters. In places where the shale is glauconitic a peculiar vermicular structure of the sediment was observed which is believed to be due to the action of mud-burrowing organisms, probably worms.

Thickness.—The thickness of the Thirindine Shale varies greatly. In the east, east of the telegraph line, it is 18 feet thick, and just west of the line, near the emergency landing ground, it decreases to five-and-a-half feet,

but farther west it increases again until it reaches a maximum of 60-63 feet at Toolonga Hills. At Thirindine it is still 52 feet thick, but from there westward the thickness decreases somewhat irregularly. In the Butte section in Second Gully it is still 35 feet, but at Second Gully Point it has dwindled to three feet and at Alinga has disappeared. At Meanarra this shale is about 15 feet thick.

5. Alinga Beds.

Derivation of name.—Alinga, four-and-a-half miles N.W. of Murchison Homestead, is a prominent point in the chalk scarps, a little more than a mile north of Mullewa Point.

Areal distribution and outcrops.—The Alinga Beds could be followed from Mullewa Point in the west to the eastern termination of our survey area, one-and-a-half miles east of the telegraph line. They form an easily recognizable zone of dark rock between the whitish Thirindine Shales below and the chalk above, but actual outcrops are poor, owing to the softness of the rock. There is much slipping so that it is often difficult to get a correct picture of the lithology of the beds. Gully erosion and subsurface erosion are cutting strongly into this zone and removing large quantities of it. About nine miles to the north-east of the area mapped the junior author found the Alinga Beds overlying the Thirindine Shales at Weerinoogudda Dam where they form the top of the escarpment north of the dam. The Alinga Beds are also probably present at Meanarra Hill south of the Murchison River; no good outcrops have been seen but they most probably occur in a zone with no outcrops between the top of the Thirindine Shale and the base of the chalk.

Lithology.—The Alinga Beds consist of dark green, always strongly glauconitic clays, shales, and sands. In general it seems that sandy components predominate to the north-east and that towards the south-west the beds become increasingly clayey and shaly. At Weerinoogudda Dam, nine miles north-east of our survey area and 21 miles east of the coast, the Thirindine Shale is overlain by greensand which forms an escarpment immediately north of the dam. No higher strata are exposed in this vicinity. Immediately west of the telegraph line, in the vicinity of the emergency landing ground, the Alinga Beds are predominantly shaly, but farther west in the Pillarawa section they are sandy throughout the lower 15 feet, changing into shales above which contain a number of gypseous layers. Still farther west at Bracken's Point the top of the Alinga Beds is formed by reddish weathering clay which changes downward into clayey greensand. In the Toolonga Hill section and to the west thereof the Alinga Beds change into almost pure glauconitic clay which here and there may contain beds or pockets of glauconitic sand such as are well exposed near the butte in Second Gully. At Alinga Point (text fig. 12) the predominating sediment seems to be a very fine sandy clay or shale of very uniform lithology.

Fossils.—The only fossils seen in these beds are belemnites, probably of the genus *Dimitobelus,* which occur in great quantity at Alinga Point, but also at Thirindine Point and in the south-western part of the Toolonga

Text Fig. 12.

Alinga Point. The darker greensands of the Alinga Beds forming the lower part of the slope are overlain by light-coloured Toolonga Chalk.

Hills. The preservation of these fossils is as a rule very poor, the guards weathering easily on exposure.

Thickness.—The thickness is small in the east. East of the telegraph line it is only 18 feet, increasing gradually to about 75 feet in the Pillarawa section. West of this there is again a decrease in thickness to 10 feet near the west end of Toolonga Hills followed by a rapid increase in the cliffs north of Yalthoo windmill to 60 feet. On the east side of Second Gully the thickness has decreased to 25-30 feet and near Alinga it increases again to 55 feet. At Meanarra there are about 22 feet of Alinga Beds.

6. Toolonga Chalk.

Derivation of name.—Toolonga Hills is the name of the highest part (about 600 feet above sea level) of the scarp north-west of the Murchison River. This scarp of white rocks is visible from the plateau south of the river many miles away.

Areal distribution and outcrops.—The Toolonga Chalk is widely distributed over the area. It forms the top of the coastal cliffs north of the Murchison River at least as far as several miles to the north of Nungajay Spring, but probably much farther. Outcrops along the coast are not good, because the slopes are everywhere covered with a crust of hard secondary travertine (''duricrust'') and the chalk can only be

seen in a few places where this hard crust has been removed. North-west of the Murchison River the chalk can be followed along the whole length of the scarps from Mullewa Point in the west to a place about one-and-a-half miles east of the telegraph line and the outcrops are generally very good (Plate I). There is much slumping in the chalk, mainly owing to the slippery nature of the underlying Alinga Beds. The result is that in places the entire slope of the escarpment down almost to the top of the Tumblagooda Sandstone is covered with slumped chalk (text fig. 13). The eastern limit of the Toolonga Chalk has not

Text Fig. 13.

Looking south at the scarp of the upper part of the Murchison House Series from the site of section 3 near north end of Plate II., with Jannawa and Pillarawa Hills in the middle of the picture.

yet been determined. As seen from the air a conspicuous belt of thick scrub which characterizes the top of the chalk scarp, bends sharply to the north-east east of the telegraph line; it is most likely that this marks the edge of the chalk outcrops. Farther east remnants of the chalk may occur in places as, for example, in the duricrust which covers the Alinga Beds on top of the escarpment just north of Weerinoogudda Dam, about nine miles N.N.E. of the eastern end of the area of our survey. South of the Murchison River small outcrops of the Toolonga Chalk occur on the north side of Meanarra Hill.

Scope.—The Toolonga Chalk forms an exceedingly well defined zone. Its lower boundary is rarely well exposed, but when seen (as in text fig. 12), seems to be sharp, though sometimes somewhat undulating. In the eastern half of the area mapped the chalk forms the top of the scarp north-west of the Murchison River, but in the west it is overlain by shales (Second Gully Shales). The boundary is rarely exposed, but in general the transition from the chalk to the shales seems to be rather sudden.

Lithology.—Lithologically the Toolonga Chalk is rather uniform throughout the entire area. It is a yellowish-white, massive, usually rather coherent rock which, however, weathers easily on the surface. At its base it contains in many places a layer of phosphatic nodules, usually not more than six inches thick. The nodules themselves are of irregular shape and are often geode-like, with characteristically cracked surfaces. The lower part of the chalk above the phosphate layer is as a rule very pure and where fossils occur they are usually more numerous in this lower part. In many places the upper part of the chalk is rich in chert

nodules which may reach large sizes, measuring six inches and more across. Concentration of chert nodules in the upper half of the chalk was observed especially at Toolonga Hills, but farther west at Alinga Point the chalk is cherty throughout and chert nodules are numerous in the first few feet above the basal phosphatic layer which is here well developed.

Fossils.—On the whole the Toolonga chalk is rather fossiliferous although the distribution of fossils is very patchy and irregular. Fragments of *Inoceramus* shells are ubiquitous, but entire shells are quite rare. As a rule the lower half of the chalk is more fossiliferous than the upper, but this does not hold everywhere because in some sections, such as west of the emergency landing ground, fossils are quite plentiful in the upper half of the chalk. In addition to *Inoceramus* the only common pelecypod is *Gryphaea* (*"Pycnodonta"*) *ginginensis* (Etheridge) which occurs in great quantities at Pillarawa and elsewhere. Other common fossils are the brachiopods *Trigonosemus acanthodes* Etheridge and *Magadina cretacea* (Etheridge), and echinoid spines, probably belonging to *Cidaris comptoni* Glauert, of which a few interambulacral plates were also found. Very important members of the chalk fauna are *Marsupites* and *Uintacrinus* whose detached plates are locally very numerous. Of the former genus there are two distinct types of calicular plates: one resembles the common *Marsupites testudinarius* (Schloth.) of the Northern Hemisphere, both the smooth and the ribbed variety being present; the second type of plate is considerably larger and indicates a calyx about twice the size of that of mature specimens of *M. testudinarius*. These plates are always smooth. They might well represent a new species of this interesting genus. Foraminifera are abundant but have not yet been studied.

Following is a list of the non-foraminiferal fauna (preliminary determinations only):

Cidaris comptoni Glauert, *Marsupites testudinarius* (Schlotheim), *Marsupites* nov. sp., *Uintacrinus* sp., *Serpula gregaria* (Etheridge), *Trigonosemus acanthodes* (Etheridge), *Magadina cretacea* (Etheridge), *Gryphaea ginginensis* (Etheridge), *Inoceramus* sp., *Ostrea* sp., *Spondylus* sp., belemnite fragments, *Scillalepas ginginensis* (Etheridge).

Thickness.—The greatest thickness of chalk, 120 feet, was measured just west of Jamawa, a small residual hill north of Pillarawa (text fig. 13); of this thickness 20 feet is duricrust and we do not feel quite certain that part of this might not consist of altered Second Gully Shale. However, even in that case the thickness of the chalk cannot be less than 100 feet. East of the telegraph line the thickness of the chalk is slightly more than 90 feet, but west of Pillarawa it decreases to little more than 35 feet at Toolonga Hills. Farther west it increases again to 55 and 65 feet at and near Thirindine. In Second Gully the thickness is again less (25-35 feet), but at Alinga it has increased to 55-60 feet. At Meanara there are about 70 feet of chalk.

7. Second Gully Shale.

Derivation of name.—Second Gully is the name of the valley of one of the northern tributaries of the Murchison River about three miles from

the sea coast and due north of Tutula windmill. The shale is well exposed all along the sides of this valley.

Areal distribution and outcrops.—The Second Gully Shale is of somewhat limited distribution. It is absent from the north-eastern half of the area where it has been removed by erosion. Owing to the general westerly dip of the entire sedimentary series it begins to appear above the chalk in the Toolonga Hills section. The outcrops are here very poor, because the thin cover of shales is almost entirely indurated and penetrated by travertine. The appearance of the duricrust is here that of a travertine (or "caliche") in which fragments of porcellanized green shales are embedded. West of Toolonga Hills the thickness of the shales increases, owing to the general north-westerly dip, and they are well exposed in Second Gully, in the valley between Second Gully and the coast, at Second Gully Point, and at Alinga. They probably form the top of the coastal cliffs north of the Murchison River, but the duricrust layer is here very thick and no outcrops of the shale were observed. South of the Murchison River the Second Gully Shale occurs at Meanarra Hill, where it forms the top of the series, but is poorly exposed owing to heavy duricrust formation.

Scope.—The Second Gully Shale forms the highest beds of the Murchison House Series, in the mapped area. Its contact with the Toolonga Chalk is never well exposed, owing partly to induration of the beds near the top of the scarps, partly to heavy slumping of the fine-grained rocks along the slopes (fig. 14).

Text Fig. 14.

Chalk slips in the scarp west of Toolonga. The chalk is *in situ* only near the top of the scarp.

Lithology.—As far as could be ascertained the lithology of this shale is very uniform throughout the area of its occurrence. It is a very fine glauconitic shale which seems to be devoid of any admixtures of other rock types.

Fossils.—No fossils were found in this shale series.

Thickness.—The greatest thicknesses of the Second Gully Shale were measured at Alinga (75 feet), along the east side of Second Gully near the Butte (92 feet) and north of Thirindine (80 feet). From here the thickness decreases eastward owing to the general rise of the strata in this direction. It was not observed anywhere east of Toolonga Hills. At Meanarra Hill, south of the Murchison River, about 45 feet of the Second Gully Shale are preserved.

8. Age and Correlation of the Murchison House Series.

The only part of the Murchison House Series which can be accurately dated by means of fossils is the Toolonga Chalk. The occurrence of *Marsupites* and *Uintacrinus* characterizes it definitely as an equivalent of the Santonian stage of the Upper Cretaceous.

As to the remainder of the sequence, more particularly the various sandstone and shale series below the chalk, no definite conclusion can be drawn. From general considerations of the nature of these sediments it seems, however, unlikely that strata of an earlier age than Cretaceous are present. The whole sequence of rocks is conformable and there are no major breaks in the sedimentation processes. On the whole there is a gradual change from coarse-grained near-shore to fine-grained off-shore sediments. The total exposed thickness of beds below the chalk is less than 700 feet to which must be added an unknown thickness of rocks below the lowest exposed beds of the Tumblagooda Sandstone. However, these lower sandstones must have been deposited fairly rapidly and the time represented by them cannot be very long.

From such general considerations it might be concluded that sedimentation in the area began probably not before the beginning of Upper Cretaceous time and certainly not earlier than some time in the Lower Cretaceous.

Contemporaneous deposits are widespread in Western Australia in a coastal belt between about 22° and 31½° S lat., seldom extending more than fifty miles inland from the shores of the Indian Ocean. The Toolonga Chalk can easily be correlated with lithologically similar deposits at Gingin and at Dandarragan, 60 and 100 miles north of Perth. Chalk deposits occur in these places with a maximum thickness of about 70 feet, carrying a fauna identical with that of the Toolonga Chalk. However in both places the thickness of the Cretaceous beds is smaller and the whole sequence apparently much less complete. Both at Dandarragan and at Gingin the chalk is sandwiched between greensands: a Lower Greensand which is 20 feet thick at Gingin and up to 70 feet at Dandarragan, and an Upper Greensand of which 140 feet are exposed at Gingin and less at Dandarragan (see Clarke, Teichert, and Prider, 1944, p. 274, and Teichert and Matheson, 1944, p. 168). The Lower Greensand is most probably contemporaneous with the strongly glauconitic Alinga Beds of the Murchison House Series, but farther

down in the section the parallelism ceases. The greensand-chalk series at Gingin rests on sandstones whose age has recently been determined as Jurassic (Walkom 1944). Below the Lower Greensand at Dandarragan is a series of sandstones (probably several hundred feet) of unknown age, tentatively assigned to the Jurassic by Forman (1935). In both sections there is an abrupt change in sedimentation from these lower sandstones to the greensands underlying the chalk. It would thus seem that these sandstones are not to be correlated with the lower sandstone series (Tumblagooda Sandstone and Butte Sandstone) of the Murchison House Series, but are older, and that no equivalents of the strata below the Alinga Beds are found in the south.

Sandstone which is lithologically similar to the Tumblagooda Sandstone occurs in many places between Geraldton and Northampton, particularly in the vicinity of Oakabella, on the railway line 20 miles north of Geraldton, but no survey of this sandstone area has been made.

Another area of fairly well known Cretaceous stratigraphy, discovered by Raggatt (1936), is situated more than 300 miles north of the Murchison River in the Cardabia Range, south of Exmouth Gulf. Stratigraphical and palaeontological information regarding this district is still fragmentary, but from published accounts (Raggatt 1936, Crespin 1938) it seems evident that there is a considerable thickness (up to 800 feet and perhaps more) of chalk, chalky clays, and marls which underlie a greensand deposit with ammonites of Maestrichtian age (Spath 1940). It would thus seem that much of the chalky deposit is of Senonian age (Campanian and older) and, judging from foraminiferal evidence (Crespin 1938), might also include Turonian equivalents.

From the Cardabia Range the Cretaceous extends southward as far as the Gascoyne River where chalk and other rocks have been recognized in bores. Nothing is at present known about the possible continuation of this Cretaceous belt along the east side of Shark Bay, but in the vicinity of the southern end of Shark Bay there are numerous outcrops of white shale which undoubtedly represent some part of the Cretaceous. That most of the sand plain between Shark Bay and the Murchison River may be underlain by Cretaceous sediments will be pointed out below. It is thus possible that a more or less continuous belt of Cretaceous sediments extends from somewhere south of the Murchison River northward as far as Exmouth Gulf.

IV. GEOLOGICAL HISTORY OF THE AREA.

At some time during the Lower or early Upper Cretaceous an area of some relief must have existed east of the area under review, the coast running somewhere east of 114½° E. long. A large river flowing to the west or west-north-west entered the sea, approximately where the present lower course of the Murchison is situated, and built up a large delta which was gradually pushed westward. The size of this delta was at least 1,000 square miles, though it may have been much bigger. Only some parts of the western half of this delta have been investigated and from the uniformity and smallness of the sand grains one may conclude that, when this part was being built, the river furnishing the sediment drained a wide plain surrounded by hilly country. During this time the

sedimentation area must have been subsiding, but so slowly that subsidence lagged behind sedimentation and the delta was gradually pushed out to sea.

As denudation continued, relief was diminished and the supply of sediments decreased. Sinking of the sea-floor continued, deltaic cross-bedding disappeared and fine-grained bedded sandstones were deposited. Further deepening of the area of sedimentation led to the deposition over the entire area of a uniform deposit of medium-grained unbedded quartz sand, up to 170 feet thick, which must have been laid down with great rapidity. Cross-bedding is practically absent from this deposit so presumably it was formed in moderately deep water at least below the zone of wave action and surface currents. Continued deepening of the sea is indicated by the appearance of glauconite in the upper part of the Butte Sandstone which can hardly have formed at depths of less than about 25 fathoms.

The deposition of the following Thirindine Shale indicates further reduction of the relief of the adjoining land or deepening of the sea and retreat of the coastline in an easterly direction. There may have been a combination of both events.

Throughout all this time, since the beginning of the formation of the delta, conditions must have been generally unfavourable for most types of life. Certain types of sand and mud burrowers constituted practically the entire fauna. Occasionally, especially during the closing stages of the deposition of the Butte Sandstone, logs of wood drifted out to sea and were buried in the sand. Some pieces are riddled by wood-borers (*Teredo?*) and must have drifted a long time before they settled down on the sea-floor. Remains of belemnites in the Thirindine Shale are so rare that it seems that they must have drifted there from some more favourable environment.

The sediments which were deposited after the Thirindine Shale indicate clearly a slow, probably more or less continuous deepening of the area of sedimentation. The glauconitic Alinga Beds may have been formed at depths anywhere between 25 fathoms and 100 fathoms, while the overlying chalk seems to indicate a further deepening of the sea below the 100 fathom line. During the time of the deposition of the Alinga Beds the nearness of the coast in the east still affected the nature of the sediments for there seems to be a change from greensands in the east to glauconitic clays and shales in the western part. Belemnites were abundant at this time.

The chalk forms a uniform sheet of sediment and indicates the existence in this area of a moderately deep sea, probably of the order of 100 or 200 fathoms, where a fairly rich neritic life flourished. *Inoceramus* was common, and also other pelecypods, brachiopods, stalkless crinoids, and other forms of life. The transition from the glauconitic Alinga Beds to the chalk is marked by a bed of phosphatic nodules. The chalk was formed during Middle Senonian (Santonian) time. This period was followed by a time of deposition of glauconitic shale which may indicate a slight rising of the sea-floor and a westward advance of the coastline.

The post-Cretaceous history of the area will not be discussed in this paper.

V. EXTENSION OF CRETACEOUS NORTH OF MURCHISON RIVER.

Forman is the only geologist who has traversed the country between the Murchison River and Shark Bay west of the Carnarvon road and he remarks on the almost entire absence of outcrops (Forman 1937), as indeed observations from the air would suggest. Some idea of the geological structure of this area could perhaps be obtained by following the coast north from the mouth of the Murchison River, where coastal cliffs 800 feet high are reported to exist. The nearest known outcrop of supposedly Cretaceous beds farther inland is about 38 miles north of Mt. Curious in the southern part of Cobourn Station where Forman (1937) observed greensand in a dry soak.

Another 35 to 40 miles farther north there are outcrops of white to yellowish shaly rocks with brown chert bands which form low hills, 40 to 50 feet high, along the road leading to Carnarvon and about seven to 10 miles east of Hamelin Pool. We traversed this area in 1941, but had no time to stop for any detailed examination. The rock seemed to resemble the Thirindine Shale, but lithologically very similar rocks are also known from the Lower Cretaceous Winning Series of the Cardabia Range, 250 miles farther north.

There are many limestone outcrops in the country south of Hamelin Pool, but these are probably Recent travertines. The country has the character of a slightly undulating karst landscape, with weathered limestone ridges about three-quarters of a mile to a mile apart, and red soil accumulating in the depressions.

Our only knowledge of subsurface geology comes from a few scattered sub-artesian bores of which only drillers' logs and no samples are available. Moreover, for most of the bores the heights of the bore sites above sea level are not known.

Of particular interest is a group of bores (Nos. 6, 7, 8 and 10) in the vicinity of Gee Gie Outcamp, on Murchison House Station, about 17 miles north of Nungajay Spring, and about 15 miles N.W. of Mt. Curious. Typical of these is No. 10.

Driller's Log.	Stratigraphic Interpretation.
0– 4 feet yellow sand ... ... 4– 12 feet red sandy clay	Surface deposits, 12 feet
12– 40 feet green clay ... ... 0– 85 feet yellow clay	Second Gully Shale, 73 feet
85–286 feet chalk	Toolonga Chalk, 201 feet
286–334 feet dark shale	Alinga Beds, 48 feet
334–341 feet, sand ... ... 341–343 feet black sandstone	Butte Sandstone, 9 feet

It is not possible from the driller's log to differentiate clearly between the Second Gully Shale and the Toolonga Chalk and it may be that part or all of the "yellow clay" between 40 and 85 feet should rather be included in the Toolonga Chalk. It is of some interest that there is no indication of the occurrence of the Thirindine Shale in these bores. Gee Gie Outcamp is about 15 miles west of Weerinoogudda Dam where considerable outcrops of Thirindine Shale are known to occur, and the disappearance of the shale in a westerly direction is in complete agreement with conditions found along the Murchison River where it peters out in Second Gully as described already in this paper.

No further bore records are available until Cobourn and Boolagoorda Stations are reached, 30 to 40 miles farther north, and it is perhaps inadvisable at this stage to attempt any detailed correlation of the driller's logs in places so far removed from the type section of the Murchison House Series. It is, however, worth recording that all bores here, after penetrating a few hundred feet of soft strata, usually marked as "clay" or "shale," reach sandy layers. In bores on Cobourn Station the first sandy beds were struck at depths below the surface varying from 170 to 373 feet and on Boolagoorda Station at depths between 403 and 450 feet. These sandy beds are mostly described either as "sand" or as "soft sandstone" and it would seem that they are most likely the northern continuation of the Butte Sandstone of the Murchison House Series. In the Shark Bay region the surface of these sandstones seems to dip towards the north-west, for in the centre of Peron Peninsula a bore was put down to a depth of 1780 feet without reaching any sandy rocks at all.

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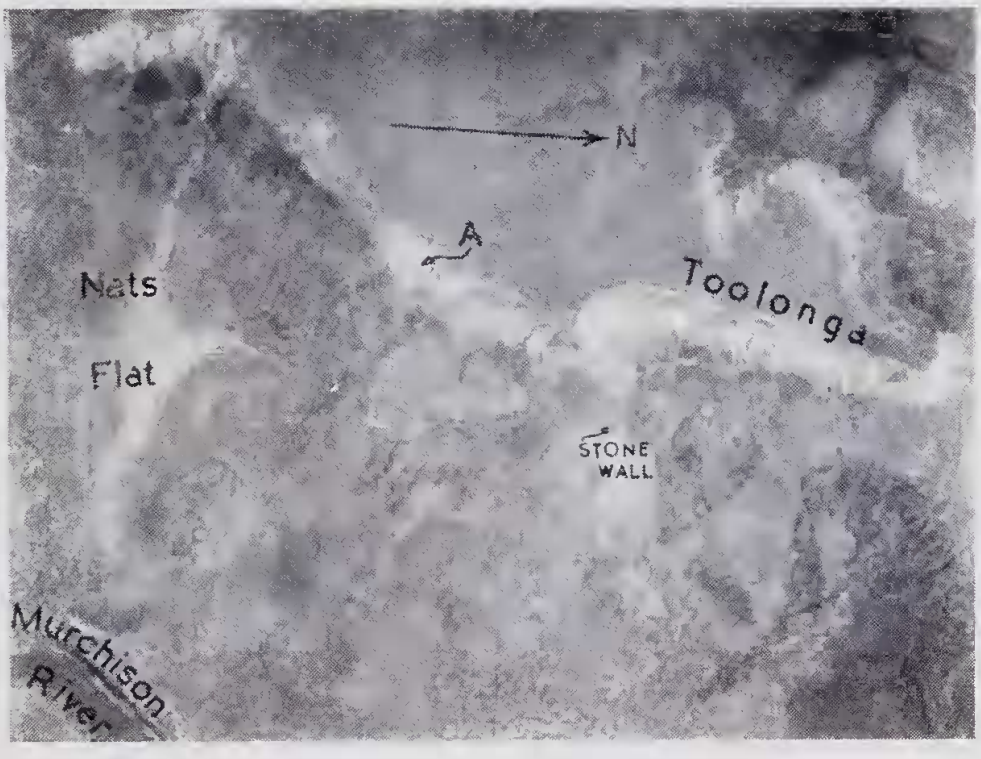

PLATE I.

Vertical aerial view of part of the country north-west of Murchison River, showing the scarp at Toolonga Hills. In front of it is the flat shelf covered with loose sand, here interpreted as Butte Sandstone. The conspicuously jointed rock is Tumblagooda Sandstone. At *A* is the part of the scarp shown in fig. 14 (*R.A.A.F. photo., Published by permission*).